Search for MSSM Higgses at the Tevatron

A. Connolly [a*]
For the CDF and D0 Collaborations

[a]Lawerence Berkeley National Laboratory, 50B-5239, One Cyclotron Rd., Berkeley, CA 94720 U.S.A.

We present an overview of searches for MSSM Higgs at the Tevatron, concentrating on searches probing the high $\tan\beta$ region. We discuss the search for $A/H \to \tau\tau$ which is soon to be completed in the Run I data and review the new tau triggers implemented by CDF and D0 in Run II, which will greatly impact this analysis. We also present the results of a Run I search for $A/Hbb \to bbbb$ performed by CDF and highlight expected improvements in this channel by both experiments in Run II.

1. MOTIVATION

The Higgs mechanism breaks electroweak symmetry in the Standard Model, giving mass to particles through its couplings. Current data from electroweak precision measurements points to a light Higgs ($M_{Higgs} < 199$ GeV @ 95% CL [1]). However, the Higgs has never been definitively observed ($M_{Higgs} > 114$ GeV at 95% CL [2]).

A Standard Model Higgs suffers from the so-called hierarchy problem. The theory needs fine-tuned parameters to accomodate a light Higgs mass. Supersymmetry offers a solution to this problem, through a symmetry between fermions and bosons.

The Minimal Supersymmetric Standard Model (MSSM) contains two Higgs doublets, leading to five physical Higgs bosons: Two neutral CP-even states (h and H), one neutral CP-odd (A), and two charged states (H^+ and H^-). At tree-level, the masses are governed by two parameters, often taken to be m_A and $\tan\beta$ [3]. When $\tan\beta >> 1$, A is nearly degenerate with one of the CP-even states (denoted ϕ). Where $m_A \leq 130$ GeV ($m_A \geq 130$), $m_A \cong m_h$ ($m_A \cong m_H$).

In this same large $\tan\beta$ region, the cross sections for some production mechanisms such as $pp \to A(\phi)$ and $pp \to A(\phi)b\bar{b}$ are enhanced by factors of $\tan\beta^2(\sec\beta^2)$. For example, with $\sqrt{s} = 2$ TeV, $\tan\beta = 30$ and $m_A = 100$ GeV, the cross sections for $pp \to A$ and $pp \to \phi$ are each of order 10 pb[4]. The cross section for $pp \to A/\phi b\bar{b}$ is smaller, but within the same order of magnitude. In the same region, the branching ratios to $A/\phi \to b\bar{b}$ and $\tau\tau$ dominate, at $\sim 90\%$ and $\sim 10\%$ respectively, independent of mass.

Due to their similar masses, cross-sections and branching ratios in the high $\tan\beta$ region, we search for both A and ϕ simultaneously. At the Tevatron, we search for $pp \to A/\phi \to \tau\tau$ (the $b\bar{b}$ final state is expected to be overwhelmed by dijet background) and $pp \to A/\phi b\bar{b} \to b\bar{b}b\bar{b}$.

2. SEARCH FOR $pp \to A/\phi \to \tau^+\tau^-$

This search is underway at CDF. The dominant issues for this analysis are: tau identification, ditau mass reconstruction, irreducible background from $Z \to \tau\tau$, and event loss at the trigger level.

Wherever not specified, we use the benchmark case of $m_A = 95$ GeV and $\tan\beta = 40$ to quote efficiencies and cross-sections.

2.1. Tau Identification

Compared to QCD jets, taus are highly collimated, leaving narrow jets with low track and photon multiplicity, and low mass.

In CDF, when selecting taus, one typically requires a jet with high visible E_T containing a high p_T track. The jet is required to be isolated in a $10^o - 30^o$ annulus around the high p_T track. The visible energy in a 10^o cone is required to satisfy low track and photon multiplicity requirements

*Current address is Fermi National Accelerator Laboratory, P.O. Box 500, M.S. 318, Batavia, IL 60510 U.S.A.

and to reconstruct a mass $m < 1.8$ GeV. Additionally, a requirement is made on the charge of the tracks in the 10^o cone when appropriate. In Run I, CDF acheived fake rates in the range 1.2 - 0.7 % for jet E_T between 20 and 200 GeV[5].

2.2. Ditau Mass Reconstruction

The full mass of a ditau system may be reconstructed [6] if the neutrinos are assumed to travel in the same direction as their parent taus, by solving the following system of equations:

$$\not{E}_x^{meas} = \not{E}_x^{\tau 1} + \not{E}_x^{\tau 2} \tag{1}$$

$$\not{E}_y^{meas} = \not{E}_y^{\tau 1} + \not{E}_y^{\tau 2} \tag{2}$$

where $\not{E}_{x,y}^{meas}$ are the x and y components of the measured event missing energy, and $\not{E}_{x,y}^{\tau 1}$ and $\not{E}_{x,y}^{\tau 2}$ denote the missing energy from each tau.

Equations 1 and 2 do not give a meaningful solution when the taus are back-to-back in the transverse plane. Therefore, we require that $|\sin \Delta\phi| > 0.3$, where $\Delta\phi$ is the azimuthal angle between the tau candidates.

When the solution to Equations 1 and 2 gives $\not{E}^{\tau 1} < 0$ or $\not{E}^{\tau 2} < 0$, the event is thrown out, causing about 50% of the Higgs signal to be lost. However, 97% of W+jets events are rejected in this way, which would otherwise be a formidable background.

We generate $A/\phi \to \tau\tau$ events in Pythia 6.203 with $m_A = 95$ GeV and $\tan\beta = 40$. After simulation of the Run I CDF detector, a ditau mass distribution is reconstructed with a mean value of 93.7 GeV with an RMS of 24.1 GeV.

2.3. Irreducible Background

The dominant *reducible* backgrounds to this analysis are QCD, $Z \to ee$, and W+jets. $Z \to \tau\tau$ is an irreducible background, but Higgs events are more efficient for this search than Z's for a couple of reasons.

First, in the high $\tan\beta$ region, A/ϕ's have a high branching ratio to taus (9%) compared to Z's (3.7%). Second, an A/ϕ is typically produced with a stiffer p_T than a Z. This means that the requirement $|\sin \Delta\phi| > 0.3$, which is nearly equivalent to $p_T^{A/\phi/Z} > 15$ GeV, is $\sim 30\%$ more efficient for Higgs events than Z events.

2.4. Triggers

Since there was no τ trigger in Run I at CDF, the analysis uses a lepton trigger requiring $p_T >$ 18 GeV, seeking events with one leptonic and one hadronic decay. Since only half of the signal events decay in this way, and of these, only 20% contain a lepton which satisfies the p_T requirement within the acceptance, the signal rate is greatly diminished at the trigger level.

This major loss at the trigger level is problematic, since the cross section drops by a factor of 4 from $m_A = 95$ GeV to $m_A = 120$ GeV, before the mass reconstruction, with an RMS of 24 GeV, can discriminate from $Z \to \tau\tau$. Therefore, in Run II, CDF and D0 are both implementing triggers designed for tau physics. Lowered p_T thresholds and new decay modes available will greatly increase the acceptance for this search.

In Run II, CDF and D0 both have lepton + track triggers and $\tau + \not{E}_T$ triggers. In addition, both experiments are triggering on events with two hadronic taus. CDF's trigger is calorimeter-based, while D0's is track-based.

The Run I search for $A/\phi \to \tau\tau$ is still work in progress, and the Run II analysis is also in the works.

3. SEARCH FOR $pp \to A/\phi b\bar{b} \to b\bar{b}b\bar{b}$

CDF performed this search in Run I. Both experiments expect to improve on the analysis in Run II.

3.1. Run I search

The Run I search at CDF [7]utilized a 4-jet trigger requiring $\Sigma E_T > 125$ GeV. Three b-tags were required based on displaced vertices, and the b jets were required to be separated in azimuthal angle, $\Delta\phi > 1.9$. To optimize sensitivity, the E_T cuts on the jets varied with mass hypothesis. For mass hypothesis below 120 GeV (above 120 GeV), the second and third b-tagged jets (first and second jets) ordered in E_T were chosen for the mass reconstruction. The search is performed in mass windows dependedent on mass hypothesis.

The product of branching ratio and acceptance ranged from 0.2 to 0.6% in the mass range 70 and 300 GeV. For a mass hypothesis of 70 GeV,

5 events were observed with 4.6 ± 1.4 expected. Only these 5 events appear in the higher mass windows. No excess above predicted is observed. Figure 1 shows the $m_A - \tan\beta$ region excluded.

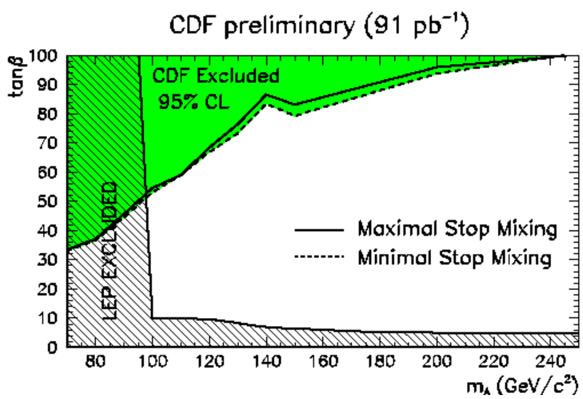

Figure 1. Region of the $m_A - \tan\beta$ region exluded by the CDF search.

3.2. Run II Improvements

At CDF, studies of $Z \to b\bar{b}$ events show an improved dijet mass resolution after correcting for muons, $\not{E}_T$, and nonlinearities in the hadronic calorimeter. Separate studies of QCD jets using similar techniques show a 30% improvement in jet resolution.

B-tagging in Run II at CDF will be improved with the new ability to reconstruct three-dimensional tracks. Extended coverage from $|\eta| < 1$ (Run I) to $|\eta| < 2$ means improve b-jet and lepton acceptance. Additionally, new triggers will also recover acceptance, including a displaced track trigger, and an improved multijet trigger.

With a new silicon detector, D0 will also be performing this search in Run II, expecting a 12% dijet mass resolution. Both experiments perform a study of their expected sensitivity to $pp \to A/\phi b\bar{b} \to b\bar{b}b\bar{b}$ in Run II, and obtain similar results[8]. We present the D0 study here.

D0 also uses a multijet trigger, requiring four jets, each with $E_T > 15$ GeV. To maximize sensitivity, mass dependent E_T cuts are made on the jets. At least 3 b tags are required. All mass combinations are plotted, and a 2.5σ $b\bar{b}$ mass window is used. With $2fb^{-1}$, D0 concludes that the Tevatron is expected to exclude $m_A < 160$ GeV for $\tan\beta = 40$ at 95% CL, and a 5σ discovery for $m_A < 115$ GeV for the same $\tan\beta$.

4. CONCLUSIONS

Run I results of the search for $A/\phi \to \tau\tau$ at CDF are to be completed soon, and a first glimpse of Run II data is on the way.

The Run I search for $pp \to A/\phi b\bar{b} \to b\bar{b}b\bar{b}$ derives lower mass limits for $\tan\beta$ in excess of 35. In Run II with both experiments searching for this decay mode, the Tevatron is expected to exclude (or make a discovery in) a significant region of MSSM parameter space. Both experiments are optimistic about improvements from triggers, jet resolution, and b-tagging to make this search even stronger than the current projections.

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